

# Technology For Expanding The Biofuels Industry

April 21-22, 1992



Chicago, Illinois



Sponsored By:

US DEPARTMENT OF ENERGY  
US DEPARTMENT OF AGRICULTURE  
RENEWABLE FUELS ASSOCIATION

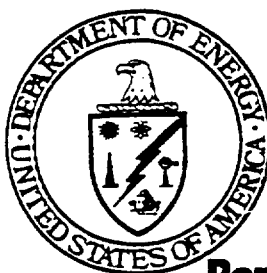
## PROCEEDINGS



# **PROCEEDINGS**

## **Technology For Expanding The Biofuels Industry**

April 21-22, 1992



Chicago, Illinois

**Renewable  
FUELS**

**Coordinated By:**

**Science Applications International Corporation**

**Under NREL Contract No.: YS-2-12080-1**

**Sponsored By:**

**US DEPARTMENT OF ENERGY  
US DEPARTMENT OF AGRICULTURE  
RENEWABLE FUELS ASSOCIATION**



April 21, 1992



Renewable  
Fuels



The U.S. Department of Energy (DOE), the U.S. Department of Agriculture (USDA), and the Renewable Fuels Association are joining to sponsor a workshop, *"Technology For Expanding the Biofuels Industry,"* planned for April 21-22, 1992, in Chicago, Illinois. Changing environmental regulations under the Clean Air Act and new developments in technology present an increasingly important opportunity for the renewable biofuels industry to meet the fuel needs of the transportation sector.

Now, more than ever, there is an urgent need for representatives from industry, government, and academia to share information about existing technologies, identify knowledge gaps, and recommend actions to accelerate the development and commercialization of the most promising biofuels technologies. The results of the workshop will help DOE and USDA define and focus their research agendas. We are confident that your expertise on the subject of biofuels positions you to make a valuable contribution to achieving the workshop's objectives.

We encourage you to take part in this important event. Enclosed is additional information and a registration form. In the meantime, if you have any questions concerning this conference, please contact Barbara Derwiler at (703) 734-5521.

We hope that you can make a commitment to this important workshop.

Sincerely,

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U.S. Department of Energy

Daniel A. Sumner  
Acting Assistant Secretary  
for Economics  
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Eric Vaughn  
President  
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## WORK GROUPS

### **FEEDSTOCKS WORK GROUP**

Chairpersons: Dwayne Buxton and Wayne Smith .....	I
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### **CONVERSION (STARCH) WORK GROUP**

Chairpersons: Michael Ladisch and Robert Schwandt .....	II
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### **CONVERSION (CELLULOSE) WORK GROUP**

Chairpersons: Lee Lynd and Lawrence Russo .....	III
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### **COPRODUCTS WORK GROUP**

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### **BIODIESEL WORK GROUP**

Chairperson: Davis Clements .....	V
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### **ECONOMICS & ENVIRONMENTAL ISSUES WORK GROUP**

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# FORWARD

These proceedings present the work group summary reports given at the "*Technology For Expanding The Biofuels Industry*" workshop held in Chicago, Illinois on April 21-22, 1992. The workshop was sponsored by the U.S. Department of Energy, U.S. Department of Agriculture, and the Renewable Fuels Association, and conducted by Science Applications International Corporation.

The main purpose of the workshop was to provide an opportunity for representatives from industry, government, and academia to share information about existing technology, identify knowledge gaps, and recommend actions required to accelerate the development and commercialization of the most promising biofuels technologies. Within this framework, the following work groups were addressed:

- Feedstocks;
- Conversion - Starch;
- Conversion - Cellulose;
- Coproducts;
- Biodiesel; and
- Economics and Environmental Issues.

Appreciation is extended to the outstanding work group chairpersons, whose reports appear in this publication. The quality of the program reflects considerable time and effort put forth by the work group chairpersons and speakers in the preparation of their presentations. In particular, a special note of appreciation to Stan Bull from the National Renewable Energy Laboratory who was responsible for conducting the work group orientation sessions. A word of thanks is also extended to the conference coordinators, Barbara Detwiler and Kathy Cooke of Science Applications International Corporation, who managed the conference activities from beginning to end.

Biofuels is an area rich with opportunities for contributing to achievement of important National objectives. Development and commercialization of biofuels technology, however, face a number of challenges in the months and years ahead. We look forward to working with you in meeting those challenges. Again, our appreciation for a job well done and the success of the Biofuels Workshop.



# **"TECHNOLOGY FOR EXPANDING THE BIOFUELS INDUSTRY"**

*The Westin Hotel, O'Hare - Chicago, IL*

*April 21-22, 1992*

## **PROGRAM**

### **MONDAY, APRIL 20, 1992**

7:00 - 9:00pm Early Registration (Executive Forum Lobby)  
9:00 - 10:00pm Chairman Meeting (State Room)

### **TUESDAY, APRIL 21, 1992**

8:00 - 9:00 Registration (Executive Forum Lobby)  
9:00 - 10:00 General Session: (Executive Forum)  
Welcome and Opening Remarks:  
*Keynote Speakers:*

- *J. Michael Davis, Assistant Secretary,*  
US Department of Energy
- *Mark Dungan, Executive Assistant to the Secretary,*  
US Department of Agriculture
- *Eric Vaughn, President,*  
Renewable Fuels Association

10:00 - 10:30 **BREAK**  
10:30 - 12:00 Overview of USDA-DOE Biofuels Programs:

- *Roger Conway, Director-Office of Energy,*  
US Department of Agriculture
- *Richard Moorner, Director-Biofuels Systems,*  
US Department of Energy

Overview of RFA-Private Sector Programs:

- *Bob Dinneen, Legislative Director,*  
Renewable Fuels Association
- *Larry Russo, Project Development Director,*  
New Energy Company of Indiana

Work Group Instructions and Announcements:

- *Richard Moorner, US DOE*

12:00 - 1:30 **LUNCHEON** (Astor Room)  
*Keynote Speaker:*

- *Becky Doyle, Director, Illinois Department of Agriculture*



**TUESDAY, APRIL 21, 1992 (continued)**

- 1:30 - 3:00      Begin Work Group Sessions  
3:00 - 3:30      **BREAK**  
3:30 - 6:00      Work Groups in Sessions  
6:00              **RECEPTION** (Adams Room)  
                    (Sponsored by Renewable Fuels Association)  
                    *Kickoff Speaker:*  
                    ● *Eric Vaughn, President, Renewable Fuels Association*

**WEDNESDAY, APRIL 22, 1992**

- 8:00 - 10:00      Work Groups in Session  
10:00 - 10:30      **BREAK**  
10:30 - 12:00      Preparation of Work Group Reports  
12:00 - 1:30      **LUNCHEON** (Adams Room)  
                    *Keynote Speaker:*  
                    ● *B. Reid Detchon, Principal Deputy Assistant Secretary,*  
                            *US Department of Energy*  
1:30 - 3:00      General Session (Executive Forum)  
                    Presentation/Discussion of Work Group Reports:  
                    ● *Work Group Chairmen*  
  
3:00 - 3:30      **BREAK**  
3:30 - 5:00      General Session (Executive Forum)  
                    Presentations/Discussions of Work Group Reports:  
                    ● *Work Group Chairmen*  
  
Closing Remarks:  
                    ● *Richard Moorer, US DOE*  
                    ● *Roger Conway, USDA*  
                    ● *Bob Dinneen, RFA*

Adjourn



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*The Westin Hotel, O'Hare - Chicago, IL  
April 21-22, 1992*

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*"Technology for Expanding the Biofuels Industry"*

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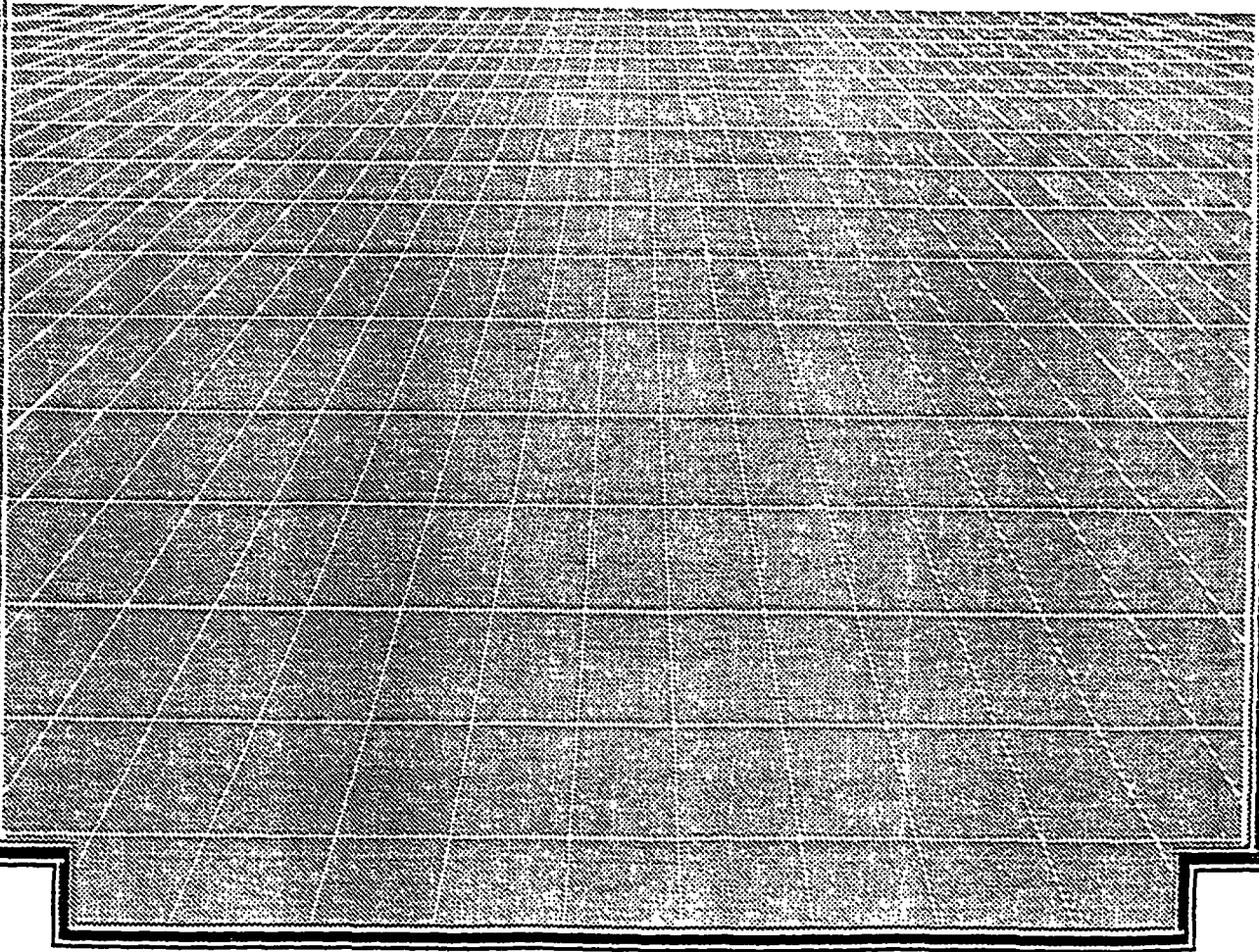
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# **FEEDSTOCKS**

Chairpersons: Dwayne Buxton and Wayne Smith





# Technology for Expanding the Biofuels Industry

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April 21 and 22, 1992  
Chicago, Illinois

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### **Summary**

Almost 80% of the land mass in the continental United States capable of producing biofuels crops is in the 18 states comprising the North Central and South Central Regions. An early research need is to target specific crops for various agroecological zones. Large increases in yields may be possible in woody species by hybridization and by selection in relatively unexploited herbaceous species. Genetic improvement research could improve yields of relatively well-developed herbaceous crops by 1-2% annually and improve the composition of biomass. Cultural management practices with positive environmental impacts need to be identified. Where cultured practices have negative impacts, research needs to be conducted to mitigate these effects. Handling, transportation, and storage of biomass will need to be addressed in part with systems analysis research, particularly in regard to feedstocks production as an integral part of existing agricultural activities. Issues concerned with genetic improvement, cultural management, environmental concerns, storage, transportation, conversion, coproducts, and economics should be addressed.

### **Background Information**

Feedstocks for biofuels include dedicated herbaceous and woody crops grown for biofuels conversion, as well as conventional grain crops, crop residues, food processing wastes, and other sources of biomass not otherwise useful. Presently, the major commercial efforts to produce biofuels are concerned with conversion of corn grain to ethanol. Other crops have potential for producing more ethanol per acre than corn grain.

The United States has the ability to produce significantly in excess of current needs for food, feed, fiber, and shelter. Millions of acres have been taken out of production by government programs, only a portion of which has been for soil conservation or environmental impact reasons. Many crops are still grown in excess of market needs and prices are supported by government programs at an annual cost of billions of dollars. Some of these crops are row crops that provide little protection to erodible soils. When grown on marginal, sloping soils, these crops contribute to erosion and non-point source pollution of surface and ground waters. Many of the target biomass energy crops are sod forming and could provide protection to erodible soils and reduce water pollution. Some of these crops could be selected or adapted for production in areas where other crops do not grow well. Several crops, after being harvested for biofuels, could provide sufficient ground cover over winter to protect wildlife and control soil erosion.

Additionally, development of biofuels crops could enhance rural revitalization in the United States. Transportation costs are such that biofuels crops will need to be converted to useable forms of energy near farming areas. Manufacturing plants, using coproducts as their feedstocks, and their satellite industries would locate around the central conversion plants, thus creating additional employment and economic development. Furthermore, biofuels crops will reduce buildup of carbon dioxide in the atmosphere because carbon dioxide will be taken up by photosynthesis of growing crops.

## **Public Policy Issues**

Public policy will play an important role in how quickly production and utilization of biofuels increase. Development of a viable biofuels crops program will be related to government policies concerned with agricultural production, agricultural exports, environmental protection, energy policies, tax exemptions, and land and water use regulations. To attract producers, energy crops must be more profitable to farmers than the available alternatives. In much of the United States, the profitability of alternative crops is greatly influenced by government programs designed to support prices, reduce production, enhance exports, or improve the environment. The effects of such policies on the attractiveness and profitability of energy crops needs to be recognized.

Biofuels have penetrated "niche" markets primarily because of the environment credit granted to fuels derived from renewable resources. For production and utilization to increase, other government incentives may have an initial effect on the development of markets so that a dependable, year round supply of biomass is available, especially from crops like forages and woody plants where a biofuels market does not exist in comparison to grains such as corn. Incentives to support pilot plants and early adoption of new technology might also influence the role of biofuels production increase.

## Production Capacity in United States

Land evaluation systems involving climate soil resource bases and crops adaptability are available. By using these systems crops can be matched to climate and soil for maximum production. The Oak Ridge National Laboratory (ORNL) recently assessed the National Resource Inventory Database to estimate the amount of land capable of growing biofuels crops in the continental United States. They determined that there were 392 million acres in cropland, or with potential for conversion to cropland, that could produce at least 5 tons per acre of dry biomass per year without irrigation (Fig. 1). Of these acres, 57% are located in the North Central Region, 22% are in the South Central Region, 12% are in the Northeast Region, 9% are in the Southeast Region, and 1% are in the Pacific Coast Region. Irrigated acres were excluded from the survey because of the energy requirement for irrigation and increased cost of production. This survey showed more land suited for herbaceous crops than for short rotation woody crops because it assumed herbaceous crops could be grown on steeper slopes than woody crops.

Major constraints to production in these areas include limited precipitation during the growing season in the Pacific Coast, Rocky Mountains, and Western portions of the North Central and South Central Regions. Excess water during part of the growing season limits production in parts of the Northeast Region. Soil erosion potential is a restriction to production in the North Central and South Central Regions. Highly weathered soils with low water and nutrient holding capacity are limitations in the Northeast and Southeast Regions.

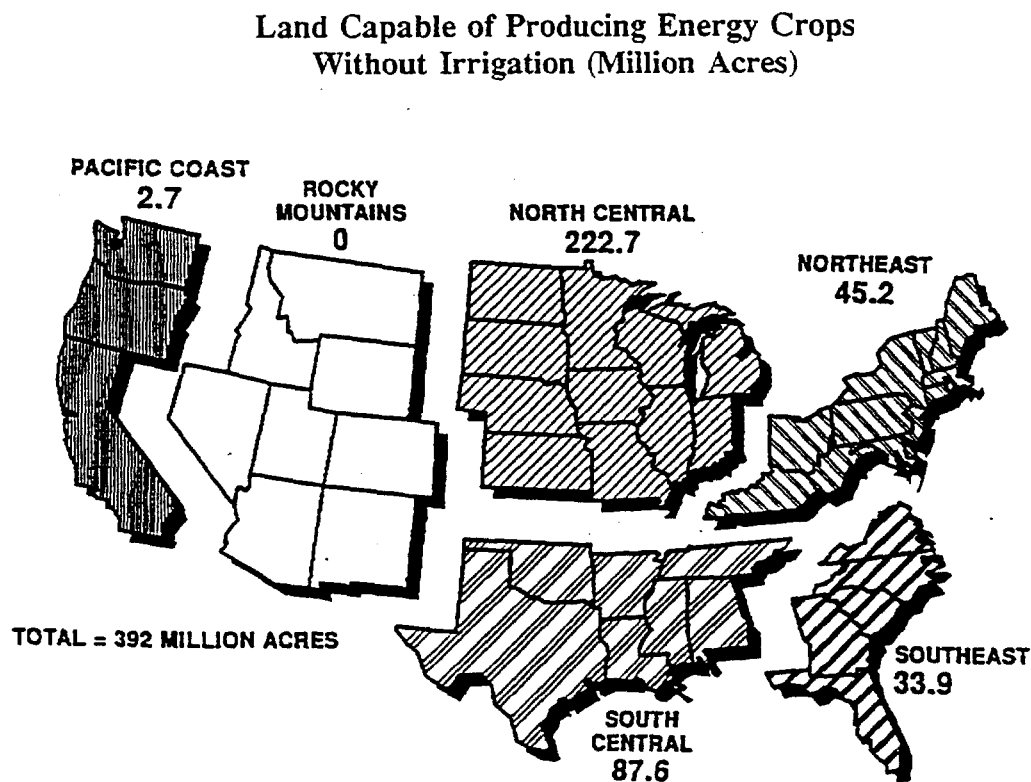


Fig. 1. Land capable of producing biofuels crops without irrigation (Oak Ridge National Laboratory)

## Targeted Crops and Biomass

To be economically useful for sustainable biomass production, trees will need to be treated and grown as crops. These woody crops will likely be grown in high densities for 5 to 7 years before harvest. The following herbaceous and woody crops were identified as having potential for biofuels production:

### Herbaceous crops

corn  
sorghums\*  
switchgrass\*  
reed canarygrass\*  
red clover  
tropical grasses\*  
tall fescue\*  
soybean  
alfalfa  
potato  
Brassicas  
Jerusalem artichoke  
small grains  
sunflower  
sugar beet  
peanuts  
other perennial warm-season grasses

### Woody crops

poplars\*  
eucalyptus\*  
black locust\*  
silver maple\*  
willows\*  
sycamore\*  
sweetgum\*  
conventional hardwoods  
pine

\*Species identified by ORNL as having high potential as cellulosic energy crop.

Additionally, forest residue could be collected after normal crop harvest. Some residue would have to be left to control soil erosion and to help maintain soil organic matter. Information is needed as to the amount of residue that might be available and the effect on the soil of removal of crop residue. Production cost for residues is borne by the harvested portion, so cost might be low. Harvest cost for residues, however, may be high because of low residue density per unit of land area.

## Breeding and Cultural Management Needs

One of the earliest priorities should be to identify which crops and trees have the greatest potential as energy feedstocks. In particular, the value of sugar and starch crops should be determined. The most critical research relative to perennial herbaceous and woody crop improvement is (1) to improve the establishment and ability to produce early returns of biomass; (2) to breed plants that persist over years; (3) to improve the ability of plants to produce stable yield over a range of environments including stressful conditions; and (4) to develop woody crops that have coppice ability and herbaceous crops that have good regrowth capability. Additionally, all species need to have lodging resistance.

One of the highest requirements for biomass species is the ability to produce high yields with high water- and nutrient-use efficiency. High yields can reduce overall production costs. Large initial increases should be possible in woody species through hybridization and in less-developed herbaceous species through selection from new and underexploited sources of germplasm. Experience with crops like corn indicates that it should be possible to increase yields of well-developed herbaceous crops 1-2% per year with a sustained, long-term commitment to genetic improvement.

Breeding efforts should also be directed toward genetic modification of crops to improve their efficiency for conversion to ethanol. For corn, this includes improving the ease of fractionating the grain into germ and pericarp, thus reducing steeping and milling requirements and the time required for processing. Additionally, it may be desirable to raise the starch content to increase the amount of ethanol that can be fermented. For cellulosic crops, desirable crop composition includes high cellulose and hemicellulose concentrations and low lignin content. For crops such as sweet sorghum where soluble sugars are desirable, breeding efforts should be initiated to raise these levels. Much progress should be possible by using conventional breeding techniques. In some situations, biotechnology may be a valuable tool for improving disease resistance, insect resistance, and other simply inherited traits.

Highest priorities for research into cultural management of biofuels crops include (1) development of cultural practices for short rotation woody crops so that trees can be grown like many other crops; (2) development of systems that result in high yields with efficient use of inputs of labor, nutrients, water, and energy; (3) development of specific information on yield potential for specific production sites; (4) determination of optimal plant densities; (5) development of information on optimal use of the landscape such as filter strips near streams to intercept nutrients, pesticides, and sediment moving across the land surface with runoff; (6) development of information on multiple cropping and intercropping that results in higher yields and that reduces the potential for erosion and other environmental and ecological concerns; (7) development of production systems that improve the timing of biomass availability so that biomass can be available on a year around basis; (8) development of systems that improve the ability to establish biomass crops; (9) development of biomass production systems that maximize the use of available farm labor and integrates biomass operations with other farm activities such that the total return to land and labor is maximized for the entire farm unit; and (10) development of production systems that meet production goals while responding to valid environmental and ecological concerns.

Research should be focused on growing environmental and ecological concerns relative to crop production. These include (1) ability to recycle wastes such as manure produced by animals in confinement onto biofuels crops; (2) increase in the use of soil-building crops and improved crop rotations so that less commercially supplied nutrients and pesticides are required for crop production; (3) use of crops that can serve as buffer areas around fragile areas and as green belts; (4) use of crops to reclaim poor soils; (5) use of crops as carbon sinks; and (6) use of crops to improve the esthetics of many open areas. Some of these goals may conflict with the need to maximize production within a given transportation distance of the conversion plant.

Production systems for biofuels crops will have to be developed to minimize soil erosion, maintain or improve water quality, provide habitat for wildlife, improve the biological diversity of production areas, and not cause gene pool pollution of natural vegetation near production areas.

### **Transportation, Storage, and Processing Needs**

Research also will need to focus on transportation and storage considerations of biomass. Some biomass contains high levels of water when harvested and is of low density. This greatly increases transportation costs. Information is needed to determine maximum distances that various forms of biomass can be transported. Hence, an early priority should be an analysis of interrelationships of land use pattern, road network, existing agricultural activities, and biomass yield potential to determine the optimal location of conversion plants.

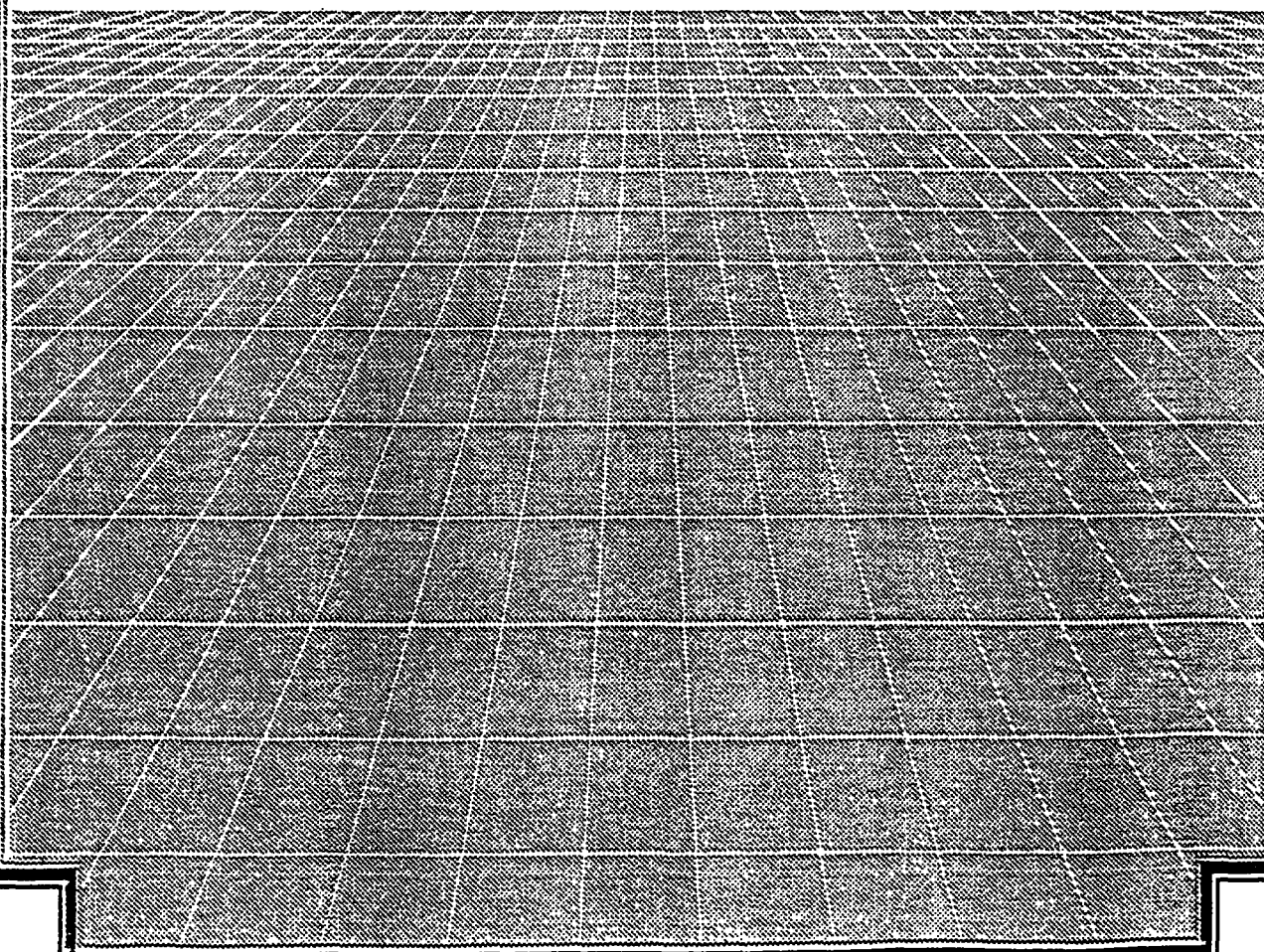
It may be possible for partial on-farm processing to remove much of the water and to increase the density of the biomass. For example, it may be feasible to use a press to remove juice from chopped sweet sorghum. Also, it may be possible to do on-farm or community (among farms) fermenting of crops with soluble sugars and to partially distill water from ethanol to reduce transportation costs. Systems analysis can be used to reveal the potential of these options.

### **Research Planning**

To address these and other related questions, scientist teams can work within specific ecological regions to focus on issues related to systems analysis, genetic improvement, cultural management, environment, storage, transportation, conversion, coproducts, and economics. These teams could include a critical mass of specialists in relevant fields and work on both herbaceous and woody crops targeted for an area. Additionally, satellite locations could be identified within reasonable travel distances where additional expertise would be available. This type of activity might involve coordinating and information sharing meetings.

# CONVERSION (STARCH)

Chairpersons: Michael Ladisch and Robert Schwandt





# Technology for Expanding the Biofuels Industry

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April 21 and 22, 1992  
Chicago, Illinois

## Conversion (Starch) Work Group

**Chairpersons:** Michael Ladisch  
Robert Schwandt

**Participants:** Rick Dunkle, Steve Eckhoff, Joe Escobar, Bob Fisher, Dick Gadomski, Kathleen Graf, Bob Harris, Fred Kuzel, Jan Lee, Ken Moser, Larry Peckous, Anthony Pometto, Matt Rendlemen, Badal Saha, Subir Sarkar, Peggy Tomasula, Ralph Willgohe, Rod Winesroll, Charlie Wyman, and others

The Starch Conversion Work Group assessed current technologies, identified research and development needs, and identified actions to accelerate the commercialization of technologies.

The processes used by the wet-milling and dry-milling industries, for converting corn to value-added products and alcohol fuels, are complex. Given the many interacting factors, and the diversity of process approaches used in the industry, the overview presented below should be taken as a rough estimate of key features in the industry. In this context, significant input was obtained during the course of the work group.

### Current Technologies

Current processing technologies in corn conversion involve the following major areas:

- Steeping
- Milling
- Starch conversion
- Fermentation
- Separations.

**Steeping.** The wet milling process involves steeping corn to hydrate the kernel, and to make it amenable to further processing to separate the germ, the starch, and other components. The physical and chemical mechanisms which are involved in this steeping process are complex. While much study has been carried out to characterize the physical parameters of steeping, much remains to be done in studying the basic chemistry of this first step. For example, the use of

alkali processing in place of acid; the gaseous addition of  $SO_2$ ; or the use of ethanol to fractionate various components of corn, are several possible approaches which might be able to enhance the separations achieved at lower cost. A committee discussion on this part of the process indicated that a decrease in the processing time of 5-fold (to achieve steeping in 8 hours) could result in very significant savings (equivalent to 1 to 5 cents per gallon ethanol) in the contribution of corn cost to the price of ethanol production. This would result in lower capital costs, lower operating costs, higher throughputs, and better quality products. Taken together, the most optimistic scenario would indicate a savings of up to 5 cents per gallon of ethanol could result. However, significant effort in a long-term research and development effort would be required to achieve such a reduction, given the complexities of wet-milling and the scale at which wet-milling is carried out.

**Milling.** Dry-milling, in comparison, uses grinding, followed by a sieving, to achieve separation of starch from the germ and the fractionation of the starch into different products. The coproducts obtained in a dry mill may not have as high value as those obtained from a wet mill, thus resulting in a higher net corn cost in some instances. Discussion of this area by the committee suggested that the conversion of dry mills to modified wet mills could in fact reduce the cost of production, increase the value of by-products, and possibly enable production of ethanol at a smaller scale while still retaining some of the economic advantages of much larger wet mills.

**Starch Conversions.** Starch obtained by either wet milling or dry milling must be liquefied and then saccharified. Excellent enzyme technology exists for carrying out these steps. Further discussion indicated that reducing the temperature swings required by this process would save energy, as long as a method for minimizing (microbial) contamination was available at the same time. Furthermore, conversion to obtain high solids sugar streams would be advantageous for downstream processing in which ethanol fermentations could give ethanol yields up to 23% (by volume) ethanol. A concentration of up to 23% (by volume) ethanol has been demonstrated by an industrial enzyme company, although it is currently not in commercial use.

**Fermentation.** Current large-scale fermentation technology predominantly utilizes continuous flow bioreactors. In this case, the fermentation broth from one bioreactor flows into another, with a number of vessels staged in series to give approximately 3 to 6 fermentation stages. This type of approach enables the yeast cells in each stage to become acclimated to the ethanol concentration and other conditions prevalent at that stage. Immobilized living cells have also been scaled up and demonstrated, although further improvement is required as well. Batch fermentations are generally used at the small scale, although the total fermentation volume in the industry is primarily continuous flow type of bioreactors.

**Separations.** Following fermentation, several separation steps are required to recover both coproducts and by-products as well as the ethanol from the beer. In this case, distillation columns give high-proof ethanol which is subsequently dehydrated using either azeotropic, corn-grit, or molecular sieve technology. There was general consensus among the work group that the rectification/dehydration technologies available or under commercial development are efficient. However, recovery of solids and non-volatile solubles is more problematic.

The key energy cost in the distillation system, appears to be associated with the removal of small amounts of ethanol at the bottom of the stripping (distillation) column leading to high "stripping" steam requirements. Combined with the downstream requirements of drying fibrous materials, and evaporating water from solubles, to give DDGS coproducts, this part of distillation is still relatively energy-intensive. Modern, totally integrated distillation/drying facilities integrate such drying and distillation operations in an energy efficient manner, albeit at a significant capital cost. Opportunities seem to exist for developing methods for removing ethanol from the bottoms of the distillation column in an energy efficient manner, and for finding alternative ways of recovering solubles and solids which would reduce the drying costs. Other opportunities also exist to recover higher value fermentation coproducts such as succinic acid, glycerol, and lactic acid from the column bottoms.

## Research and Development Needs

Identification of near-term and long-term research and development needs was based on a current cost analysis generated by the starch conversion work group. These approximate cost ranges for starch conversion are summarized in Table 1 and Figure 1. Figure 1 clearly shows that the net corn operating and capital costs are of the same magnitude of order. As Table 1 shows, the current net corn cost is approximately 40 to 60 cents per gallon. Given the variation in coproduct values, the net corn cost can vary significantly outside this range during atypical year. One way of reducing that corn cost, would be to increase the per acre yield of corn (on farm productivity) while maintaining the current cost of corn. Another approach for decreasing the net corn cost would be to improve its processing qualities, through an understanding of the chemistries involved in wet-milling and their relation to the structure of a corn kernel. Increasing the relative proportions of oil and protein would also add additional value by increasing coproduct streams.

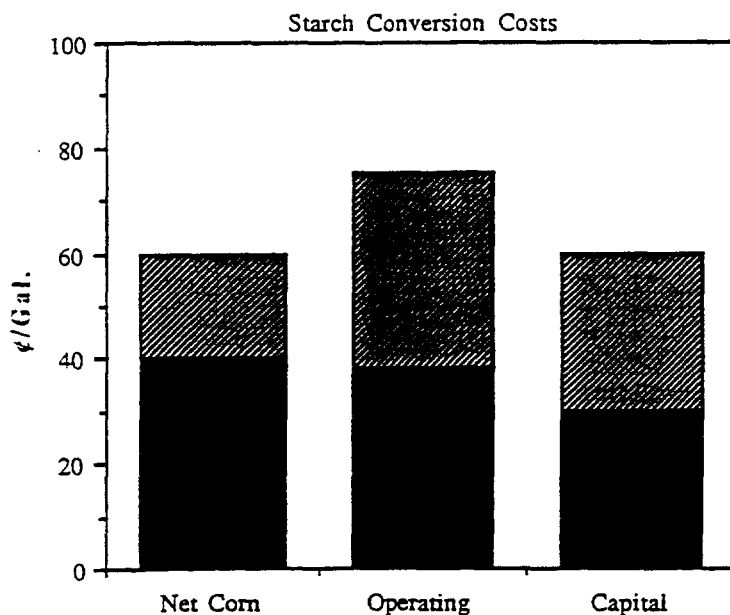



Figure 1. Bar chart showing relative importance of net corn operating, and capital costs. The low/high (solid/hatched) bars represent ranges within each category which are unlikely to be directly additive across all three categories (see text).

Operating costs are distributed principally between energy costs, enzyme and chemical costs, labor, and other costs as summarized in category B of Table 1. Capital costs, item C together with labor costs, (item B) are sensitive to scale. Larger wet-milling plants have a significant advantage in this regard. In addition, there is a relationship between energy efficiency and capital costs. If energy efficiency is desired, one approach is to further integrate the engineering design of the plan to make better use of the energy through heat exchangers. This, in turn, results in a higher capital cost; consequently, there are some trade-offs between the two categories.

**Table 1.**  
**STARCH CONVERSION**  
**Approximate Costs**

	¢/gal
A. NET CORN	40 to 60
B. OPERATING	
Energy Fuel (Steam)+	10 to 20
Electricity++	5 to 10
Enzymes Liquefaction	1 to 1.5
Hydrolysis	2 to 3
Chemicals + Other	1.5 to 2.5
Labor	8 to 22
Maintenance	7.5
Taxes and Insurance	1 to 3
Overhead	2 to 6
Subtotal (Corn + Operating)	78 to 135
C. CAPITAL (Scale Sensitive!)	30 to 60
TOTAL	108 TO 195

Best Case  
 +34,000 to 41,000 Btu/gal  
 ++1.2 to 1.4 kwh/gal.


 Dotted line indicates capital  
 and energy costs can be  
 inversely related

Based on this analysis, the committee feels that research and development can lead to improvements, which will incrementally reduce costs in more than one category. For example, improved enzyme hydrolysis of starch materials by low temperature processes, could incrementally impact both energy requirements and capital costs. Reduction or removal of solubles by upstream processing (i.e., more complete fermentation, molecular filtering, or sorption) could reduce both capital and energy costs associated with drying.

There are many major research and development opportunities and challenges which face bioprocess engineers for improving the process. These include:

1. The application of bioprocessing engineering and applied microbiology to improve the operation of immobilized cell systems, and continuous bioreactor fermentors. There are several new microorganisms which look very attractive in the laboratory (for example, *Zymomonas* and genetically engineered *E. coli* which ferments pentoses). The genetically engineered *E. coli* is still a relatively recent development. In comparison, scale-up of fermentations involving *Zymomonas* have been attempted, but a lack of robustness on the part of the microbial fermentation has proved to be limiting. Bioprocess engineering applied to such a system on a developmental scale could prove to be valuable by defining conditions and mechanisms by which a stable fermentation would be achieved.

In addition, other types of fermentation for yielding solvents such as acetone/butanol/ethanol could also prove to be interesting as a source of other oxygenated products. In this case, the fermentations use microorganisms which are strictly anaerobic (oxygen is toxic) and would present another type of challenge for bioprocess engineers.

2. The energy efficient recovery of coproducts (both solids and solubles) could result in another significant reduction in energy costs. In this case, a hypothetical process which would remove the fibrous insoluble materials without drying could be envisioned. Concept development and fundamental research may be a useful component of such a program, since changes in this part of the wet-milling process could benefit from radically new approaches if such approaches exist. This might mean the combination of microbial and biochemical technology together with the unique chemistry of the bottoms products in order to achieve separation which significantly reduces or eliminates drying energy. While success in such a program would be far from assured, the development of membranes, specialty enzymes, presses, and other type of alternate equipment could prove to be interesting. If successful, such an area could have a tremendous impact in reducing the energy consumption of the current distillation processes and save up to 5 cents per gallon.
3. The third major area is improving the up-front milling and down-stream processing, to fractionate corn into value-added products in a more efficient manner, to give better quality oil, protein, and fiber while decreasing processing time. This again would be an area of longer term research and development, and would require significant effort before realistic gains could be achieved. Nonetheless, improvements in this area and implementation by the industry could again prove to have a tremendous impact on wet-milling costs.

Other research and development recommendations are listed in Table 2. One area which is not directly related to processing research, but rather research on the properties of ethanol vs MTBE, includes the addition of agents to ethanol which might increase pipeline fungibility, and therefore, enable petrochemical companies to ship large quantities of ethanol through existing pipelines. Efforts at more effectively marketing the benefits of ethanol could prove useful in increasing the perceived value so that its prices is more consistent with its value as an octane booster.

Table 2.  
RESEARCH AND DEVELOPMENT RECOMMENDATIONS  
Starch Conversion

Area	Issues
Steeping/Milling	Size/Throughput
Conversion	
Starch	Low temp. operation; Minimize contamination at low temperature
Non-fermentables	
DDGS } Other }	Increase Coproduct Values (reduce drying energy)
Fermentation	
Batch	Other Products
→ Continuous Flow Bioreactor	{ Applied Microbiology (BioChE) (Bioprocess Eng.) }
— Immobilized Living Cells	{ Diffusion Contamination }
Separations	
Concept Development	
Bioprocess Eng.	{ Stripping Drying }
Ethanol vs. MTBE	Pipe Line Fungability Reducing Vap. Pressure Marketing (MTBE/EtOH at refinery)

### Actions to Accelerate Commercialization of Technologies

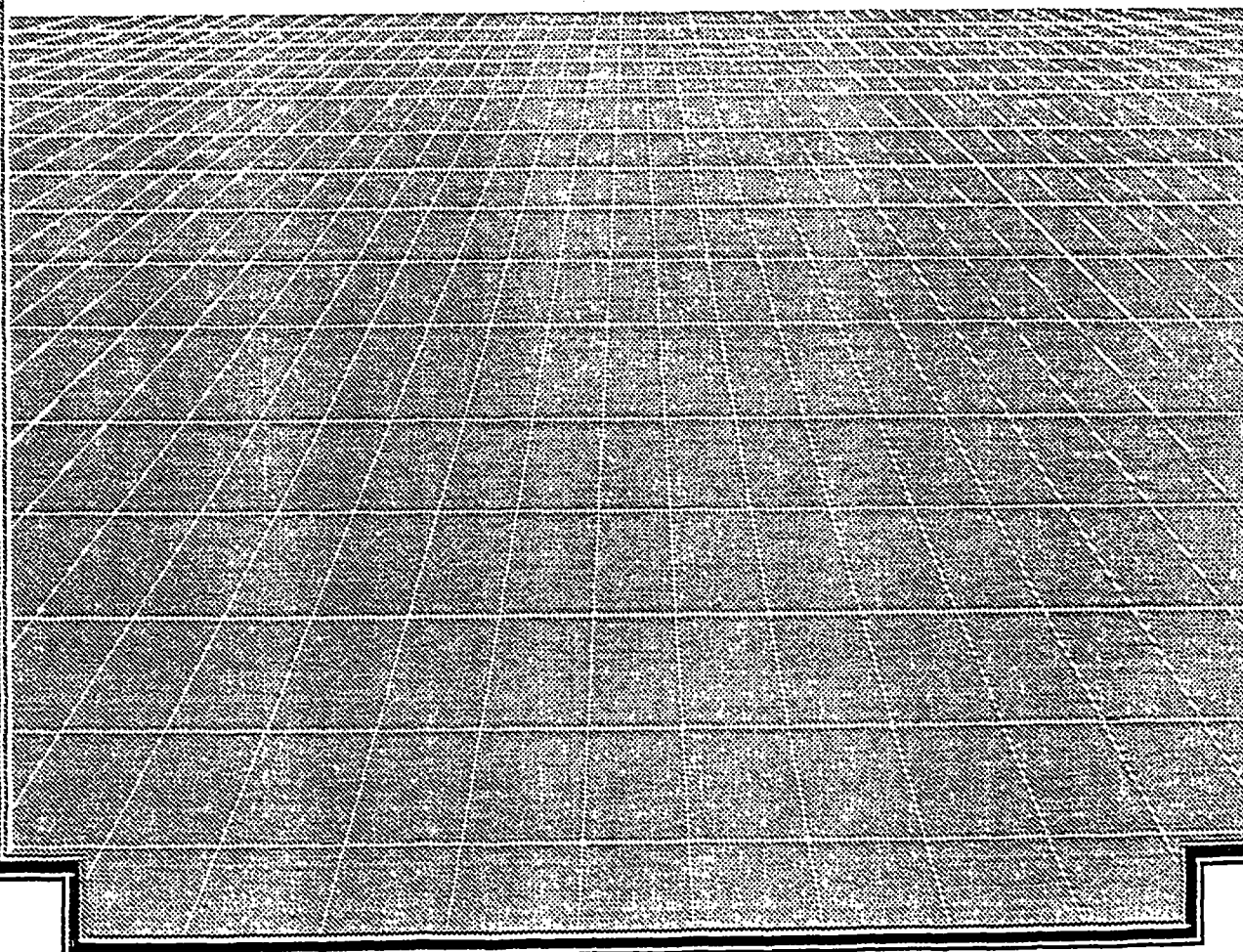
The incremental improvement of the wet-milling and fermentation processes is a current and on-going activity in the industry. This has likely resulted in significant cost reductions (in the range of 1 to 5 cents per gallon) in ethanol production. Further improvements will require significant research and development efforts to understand some of the mechanisms, chemistry, and physical properties of the complex streams involved in the wet-milling process. In this context, enzyme hydrolysis, bioprocess engineering of fermentation technologies, improvements in the wet-milling technology, and concept development in new approaches for separating water from wet-milling products is needed.

A number of initiatives would be very useful in assuring progress. This includes an investment in research and development under the auspices of graduate research training programs in the universities. The benefits will be improvement in our fundamental knowledge of the process; development of new process concepts; and perhaps most importantly, generation of the availability of trained bioprocess engineers who could join the industry and catalyze its growth over the coming 10 years. In addition, continuing dialogue between industry, government, and universities at national meetings of this type held on a semi-annual basis, could be useful in communicating developments made in laboratories throughout the nation which could positively impact the wet-milling processes. A sustained research and development mentality is critical to improving the technology base of the industry. Without it, major improvements in the production of alcohol and other fermentation products would be difficult to achieve. However, the adaptation of new technologies resulting from research will still be strongly dependent on product champions and industrial companies who are willing to take the risks associated with adapting new processes and technologies for improving the efficiency, profitability, and value of fermentation products derived from corn.



# CONVERSION (CELLULOSE)

Chairpersons: Lee Lynd and Lawrence Russo





# Technology for Expanding the Biofuels Industry

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April 21 and 22, 1992  
Chicago, Illinois

## Conversion (Cellulose) Work Group

**Chairpersons:** Lee Lynd  
Lawrence Russo

**Participants:** Andy Baker, Wayne Barrier, Bruce Dale, Roger Esker, Roger Faulkner, Irving Goldstein, Karel Grohmann, Granville Hahn, Thomas Hayes-Morrison, Norman Hinman, Nancy Ho, William Holmberg, Lonnie Ingram, Thomas Jefferies, Raphael Katzen, Jim Kerstetter, George Lightsey, Loren Luppés, Ed Matovich, Carl Reeder, Matt Rendleman, James Reynolds, Sharon Shoemaker, Earnest Stewart, David Swanson, Gary Welch, Paul Westgate

### Overview

The Cellulose Conversion Work Group was comprised of individuals representing industry, academia, and government. The group addressed and agreed on the following:

1. A timetable for the development and implementation of technology for converting cellulose to ethanol in terms of short term and long term goals;
2. Research and development needs with respect to pretreatment, acid hydrolysis, biological conversion, and other process considerations; and
3. A set of action items suggested in the area of establishing a broad framework; support for activities in the private sector; and providing information, guidance, and interaction.

### Short Term Goals (1 to 5 years)

- Develop and implement practical technology for corn fiber to ethanol.
- Bring on line one or more commercial plants for ethanol production from cellulosic substrates taking advantage of "niche" opportunities (comprised of local circumstances that

offer low cost raw materials, capital, or operation).

- Pursue aggressive research to lower costs anticipating and ideally demonstrating biomass conversion at an energy crop supplied facility.
- Develop a private sector funding base.

### **Long Term Goals (5 to 10 years)**

- Expand cellulose-based production capacity, initially in niche situations.
- Demonstrate technology allowing cost-competitive production on a large scale from energy crops.

### **Research and Development Needs**

#### **Pretreatment**

- Systematically compare and evaluate pretreatments in a total process context (including environmental aspects).
- Develop a better understanding of how pretreatment works and factors impacting effectiveness.

#### **Acid Hydrolysis**

- Concentrated Acid: Examine prospects for economical acid recycle and/or recovery, increased reaction rate, and environmental impact minimization.
- Dilute Acid: Examine prospects for increasing sugar yields, reducing vessel costs, and minimizing environmental impacts.

#### **Biological Conversion**

- Need an ongoing systematic comparison of biological processing options.
- Develop and improve organisms and systems that allow consolidated processing.
- Develop and improve organisms and systems to use all convertible biomass components (notably hemi-cellulose), with a minimum of pre-fermentation processing.
- Investigate continuous processing and innovative bioreactors for processing cellulose-substrates.

- Learn how cellulase components from a variety of sources interact to accomplish hydrolysis.
- Examine the economics of cellulase production, the benefits of varying cellulase composition, and enzyme loading optimization in the context of cellulose conversion.
- Evaluate biological conversion process inhibitors and tolerances.
- Investigate and evaluate "biomass refining", processes, including product identification, wherein non-ethanol products contribute significantly to product revenues.

### **Other Process Considerations**

- Address use or disposal of residues and/or by-products.
- Identify low cost materials of construction.
- Identify and examine substrate-specific factors impacting process performance.
- Start feeding trials and the USDA approval process for genetically engineered organisms.
- Examine opportunities for minimizing in-plant energy flows.
- Investigate processing and value enhancement of lignin.
- Place conversion in a broader context by performing system level analysis and comparative process evaluation in terms of factors such as environmental impact, cost effectiveness, and energy balance.
- Improve mechanisms for information transfer among all sectors in the area of conversion as well as related matters.
- Examine opportunities for combining starch and cellulose based technology to the mutual benefit of both.

### **Suggested Action Items**

#### **Broad Framework**

Establish a consistent policy environment based on sound environmental and economic analysis.

Research and development support for expanding biofuel production from indigenous resources needs to be increased to be commensurate with the potential benefits.

## **Private Sector**

Provide increased support to existing industries to accommodate testing and demonstration of potentially cost-effective technology for lignocellulose conversion within the context of an existing infrastructure.

Provide support for new industries targeting lignocellulose conversion to biofuels.

## **Information, Guidance, and Interaction**

Government and the conversion and biomass production industries working together could increase the visibility and accessibility of objective information about biofuels to policy makers and the public.

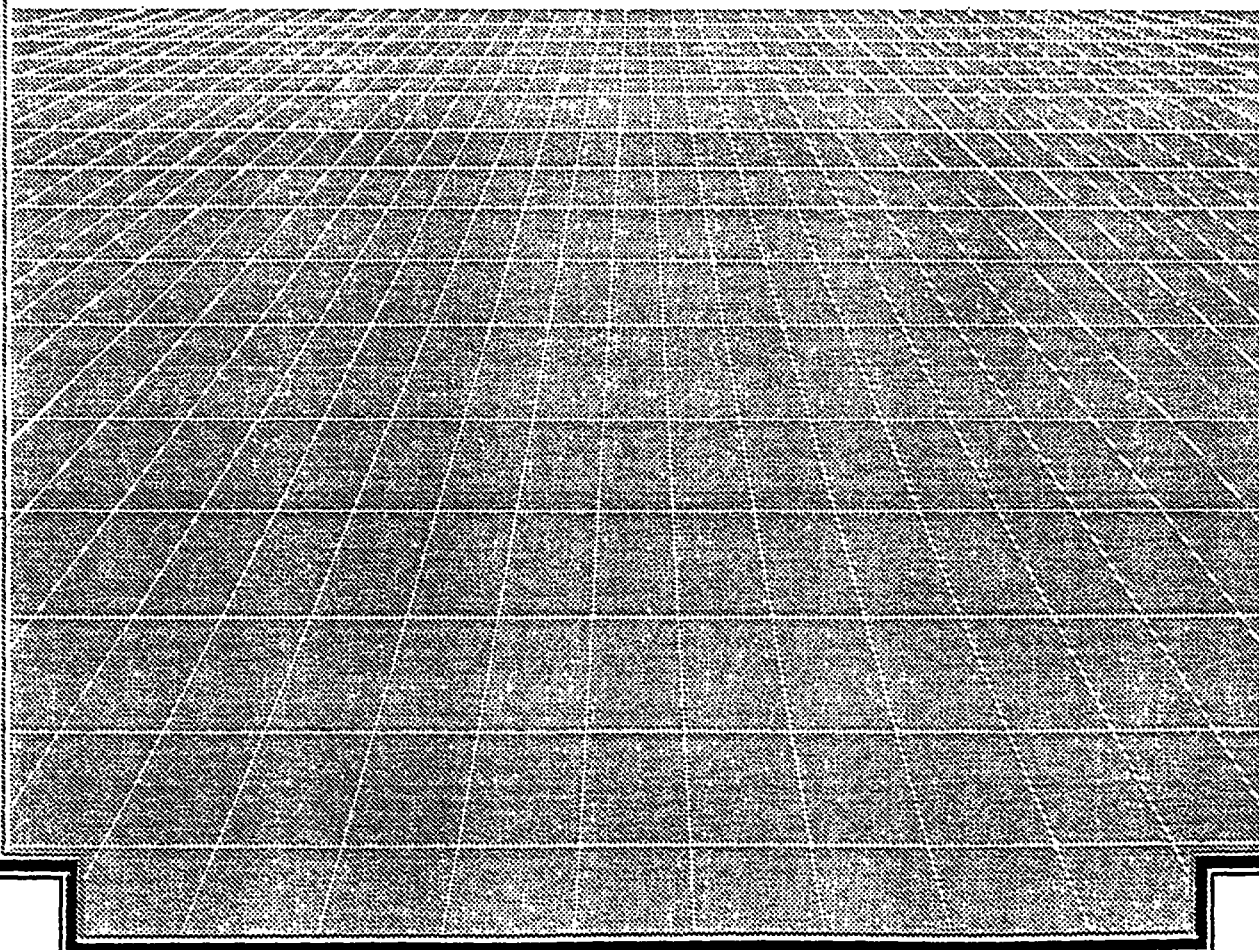
An open expert task force with broad representation could:

- Oversee establishment of an accessible economic model to guide research and to be used as a tool for business decisions.
- Evaluate alternatives and suggest strategic commercial and research directions.

Develop positive interaction and participation among biomass producers, industry, government (at all levels), and academia directed toward improving technology for cellulose conversion in a manner responsive to local needs.

# COPRODUCTS

Chairpersons: William Tallent, Linda Schilling, and Ruxton Villet





# *Technology for Expanding the Biofuels Industry*

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April 21 and 22, 1992  
Chicago, Illinois

## COPRODUCTS WORK GROUP

Chairpersons: William Tallent  
Linda Schilling  
Ruxton Villet

### **Coproducts Concept**

- In bioprocess systems for ethanol production, a judicious selection of higher value coproducts manufactured from the "unused" streams would effectively lower the cost of ethanol production and eliminate the need for tax incentives.
- Ethanol and the accompanying coproducts can be regarded as equal partners in a profitable ensemble.

### **Feedstock Opportunities**

- There is an array of biomass components offering opportunity as feedstocks for coproduct manufacture, e.g., hemicellulose, cellulose, lignin, protein, lipids (oils).
- To find opportunity for using carbon dioxide from ethanol fermentation is challenging (Possibilities include bioconversion to acetic acid and use of CO<sub>2</sub> in supercritical fluid extractions).

### **Product Opportunities**

#### Near Term

- Cellulosics to ethanol.
- Industrial enzymes.
- Specialty polypeptides.

- Lactic acid (for polymer production).
- Zein (structural protein) conversion to polymers and other industrial products.
- Cellulosics and lignin conversion to nonfood fibers, composites and other value added products.

### Long Term

- Carbon dioxide conversion to acetic acid.
- Use of CO<sub>2</sub> in supercritical fluid extractions.
- Protein conversion to specialty polymers, adhesives, etc.
- Utilization of steep liquor.
- Upgrading of biomass protein components to human food.
- Lignin "cracking" for novel products.

### **Process Opportunities**

#### Nearer Term

- Fractionation/pretreatment.
- Solids handling.
- Hydrogen sources for carbon dioxide conversion need to be evaluated to minimize CO<sub>2</sub> production.
- Novel alcohol producing organisms need to be developed.
- Process integration: chemical engineering optimization of pretreatment, conversion, and recovery components. Application of process engineering economic evaluation.

#### Longer Term

- Supercritical fluid extraction process design.
- Feedstock design - total systems approach to genetic engineering and other manipulations to optimize process.
- Evaluation of heterofermentation systems - the need for genetic engineering manipulation and separation processes.
- Chemical conversion processes.

### **Process Engineering Issues**

- Process control: the use of expert systems.
- Sensors: these are needed for continuous on-line measurement.
- Design and operation of continuous as opposed to batch systems.
- Cheaper, more effective equipment and construction material.
- Process validation for scale-up criteria and methodology.

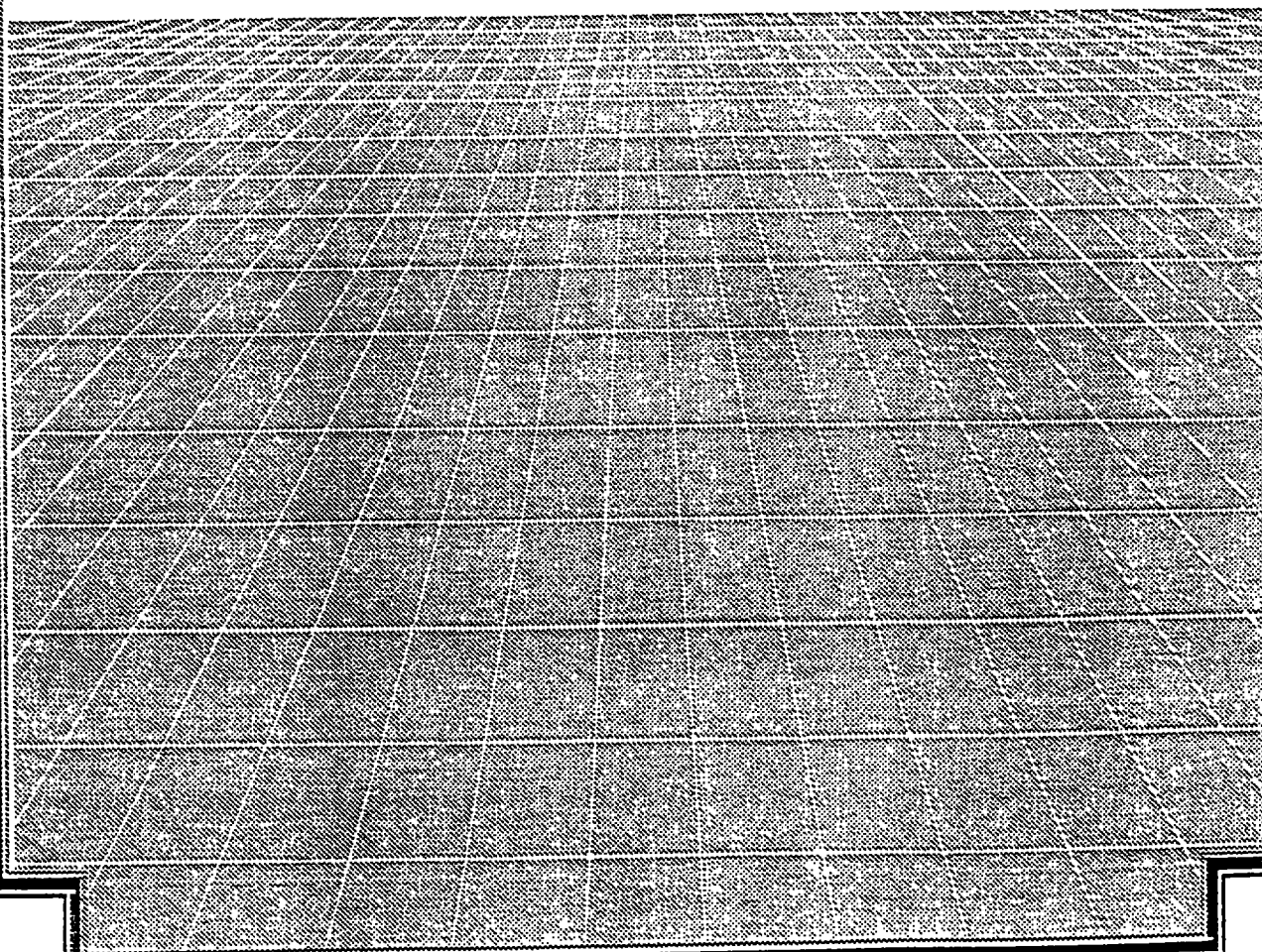
## Technology Transfer and Commercialization

- For success in coproducts development (and thus of ethanol production) industrial involvement is essential.
- Cooperative research and development agreements (CRADAs) between government and private industry, in line with the Federal Technology Transfer Act, are key.
- Reduce investment risk for biofuels through refinement of USDA/DOE/University/Industry interaction mechanisms to clarify the coproduct "opportunity umbrella" for basic and applied research.



# BIODIESEL

Chairperson: Davis Clements





# Technology for Expanding the Biofuels Industry

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April 21 and 22, 1992  
Chicago, Illinois

## Biodiesel Work Group

Chairperson: Davis Clements

The members of the work group shared their experiences and approaches to the general topic of the production, use, and role of biodiesel as an alternative fuel. The work group benefitted from a blend of government, academic, and industrial participants with experience ranging from developers of basic technology, to those engaged in production and testing of biodiesel fuels, to industrial representatives engaged in commercialization of biodiesel production.

The introductory phase of the work group revealed that there was no consensus on a definition for biodiesel. As a result, a theme throughout the work group was the revisiting of the definition until a workable consensus was reached. The work group entered into a process of issues identification and prioritization that resulted in six priority needs and a plan of specific actions required delineated by sector (industry, government, and research).

### Biodiesel Definition

Currently: the esters derived from oils and fats from renewable biological sources.

Needed: A broadly accepted, performance based definition.

### Top Research and Development Needs

- Large scale demonstrations and emissions testing to EPA standards.
- Develop a generic performance standard to define biodiesel. (Implicit is the expectation that biodiesel will perform as a direct substitute for conventional diesel fuel in terms of motor performance with no modification of the motor.)
- Assessment of the economics of the production and use of biodiesel and development of policy incentives to promote use of biodiesel in appropriate settings.
- Develop uses and markets for the coproducts of biodiesel production, particularly glycerol.

- Conduct environmental life cycle analyses comparing biodiesel to conventional diesel fuels.
- Provide accurate public education regarding the advantages and disadvantages of biodiesel fuels based upon the results generated from the efforts recommended above. The education component also needs to include organization for "crisis management" in situations of misinformation.

### **Industry Roles**

- Cooperate with DOE/USDA on demonstrations.
- Develop a generic product definition and performance standards.
- Work with EPA on acceptance of biodiesel as a fuel, including acceptance of emissions testing results and issuance of a fuel waiver prior to acceptance.
- Participate in public education efforts.

### **Government Roles**

- Support resource screening, development, and testing programs.
- Support the vehicle demonstration and testing program.
- Support emissions testing and fuel certification efforts.
- Address questions regarding safety, toxicity, and biodegradability of biodiesel fuels and their production.
- Develop policies to promote appropriate use of biodiesel.
- Participate in public education efforts.

### **Research Community Roles**

- Screen and test sources of improved feedstocks to produce biodiesel.
- Collect and disseminate data on the production and performance of biodiesel fuels.
- Engage in development of uses for biodiesel coproducts.
- Conduct environmental life cycle analyses.
- Collaborate on vehicle research and demonstration programs.

- Document the performance of biodiesel in terms of engine performance, emissions, etc.
- Develop process improvements and effluent technologies for biodiesel production.
- Conduct economic analyses evaluating the use of biodiesel in comparison with conventional diesel.
- Participate in public education efforts.

### **Recommended Next Step**

A Biodiesel Work Group to coordinate and advance efforts in the commercialization of biodiesel fuels is needed. The work group desires to continue the efforts begun in Chicago. The Biodiesel Work Group could include representatives from: DOE, USDA, EPA, research community (universities, Federal labs, etc.), and industry (crushers, producers, commodity associations, fuel user associations, and engine manufacturers).

Biodiesel is a fuel that is ready for the market. Commercial technology exists for producing biodiesel from some specific oilseeds and research is underway to expand the production technology. Vehicle demonstrations and emissions testing are needed to establish the appropriate niches for utilization of biodiesel fuels and to gain public awareness of its capabilities. The industry is proceeding towards introduction of biodiesel in several urban air quality non-attainment areas, and needs the collaboration of government to secure success.



# **ECONOMICS & ENVIRONMENTAL ISSUES**

Chairpersons: Donald Klass and John Miranowski



# Technology for Expanding the Biofuels Industry

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April 21 and 22, 1992  
Chicago, Illinois

## Economics and Environmental Issues Work Group

**Chairpersons:** Donald Klass  
John Miranowski

**Participants:** Jerry Allsup, Stan Bull, Craig Chase, Roger Conway, Ray Costello, Brian Davis, Bob Dinneen, Larry Douglas, Burton English, Rick Farnsworth, Annick Fraissinet, Erik Funegard, Granville Hahn, Mike Hammig, Thomas Hayes-Morrison, Ben Henneke, Howard Hinton, Jim Hrubovcak, Terry Jaffoni, Betsey Kuhn, Ken Johnson, Russell Lambert, Hyunok Lee, Ron Mittelhammer, Richard Moorer, Terri Moreland, Russell O'Connell, Mark Peters, Jack Ranney, Thyrele Robertson, John Ryan, Subir Sarkar, Regis Scheithauer, Susan Stefanek, Anthony Turhollow, Jane Turnbull, Shaine Tyson, Mike Voorhies, and others

The first morning was a discussion of fuel ethanol with all participants of the Economics and Environmental Issues Work Group. The group was then divided into four subgroups due to the large number of participants for the afternoon meeting. Each subgroup addressed one of the following topics.

1. Environmental
2. Ethanol from Corn
3. Ethanol from Cellulosics
4. Ethanol from Biomass and Wastes.

On the second morning, all participants met together to review the results and arrive at a single position by consensus.

### **Critical Issues**

- Long-term role as fuel ethanol and/or component
- Must be competitive alone
- Action necessary by refiners to reach multi-quad sales
- Demonstration of ethanol production from non-corn feedstock
- Feedstocks (woody biomass and wood residues)
- Federal policy.

## **Economic Positions**

- In order for fuel ethanol to be successful it must be competitive with gasoline -- as an octane enhancer it must be economically competitive with other oxygenates. Some intangible environmental benefits should be included in sales price of fuel ethanol.

## **Excise Tax Exemption Blender's Tax Credit**

- Need to continue tax benefits and make them more flexible for fuel ethanol (In certain situations, flexibility needs to be made available to the distributors of fuel ethanol or fuel ethanol blends in order for them to take advantage of the tax exemption benefit or the blender's tax credit). Current inflexibility in law should be relaxed slightly to make it easier to obtain benefits.

## **Economic Appreciation**

- What is wrong with our market? Something must be, because fuel ethanol is not selling the way it should, despite facts that: compared to MTBE, ethanol has a lower manufacturing cost per unit of oxygen blended into gasoline, and per octane unit when alcohol is used as an octane enhancing component.

## **Information Dissemination**

- Consumer education (Major factor in the transfer of fuel ethanol to the market place as a competitor with MTBE)
- Technology transfer (Major factor in the limitation of fuel ethanol usage as a competitor with MTBE)
- Government database accessibility (Not accessible to those who need this information in order to make decisions).

## **Refinery Action**

- A must!
- Clear-cut pipeline transport demonstration of blends and continuation of this to reach the next plateau above 1 billion gallons, about 5 to 6 billion gallons per year in sales of fuel ethanol.

## **Other Economic Issues**

- Effects of fuel ethanol sales on:
  - Corn prices (Favorable: it supports the price of corn, gives the farmer an alternative market for this product [particularly in the Midwestern corn belt], and tends to sustain the prices)

- Other Ag products
- World trade
- Commodity programs (Possible impact of increasing fuel ethanol sales on animal feed prices).

## **Policy Issues**

- Biofuels industry policy harmonization (the integration of different agency policies in such a manner that they aim at the same target instead of working in opposite directions at times). Most important to harmonize:
  - Ag policy
  - Energy policy
  - Environmental policy
  - Economic/tax policies.

## **Environmental Issues Where R&D Is Needed**

- Biomass production:
  - Siting and scale-up
  - Effects of farming practices on soils and water (Soils from the standpoint of removal of the nutrients -- water from the standpoint of pollution runoff and contamination by chemicals, such as insecticides, fertilizers, etc.
  - Large-scale non-corn feedstock development (Could have major environmental impact and should be assessed and evaluated in detail).
- Ethanol production:
  - Air and water quality
  - Waste generation and disposal.

The following research recommendations were judged highest priority of all possible research projects.

- Ethanol utilization:
  - Understanding real effects of ethanol and other fuel components on regulated pollutants - highest priority. (Recommend an independent analysis by one or more groups to answer questions related to regulated pollutants)
  - Trading of NO<sub>x</sub> and O<sub>3</sub> credits (Trading of these credits between fuel ethanol systems or possibly stationary and mobile systems so that a mechanism could be developed and put into place legislatively that would permit fuel ethanol producers and users to take NO<sub>x</sub> and ozone credits in the same way the fossil fuel industry can take SO<sub>x</sub> credits).

## **Ethanol From Corn R&D Needs**

- Further reduction in energy costs - highest priority (More research is needed in order to

reduce the production of ethanol cost of ethanol from corn)

- Total-kernel conversion (Increasing the yield of fuel ethanol by fermentation improvements. Ethanol yields could be increased from the current level of about 2.6 gallons per bushel to about 3 gallons per bushel of corn. Research should be done in order to permit this higher level to be achieved.)
- New technologies (Several new technologies are being developed that could be applied to improve corn fermentation)
- High-value products in broth (Indepth analysis should be done to try to locate those materials present in the broth that are possibly high-value)
- Value enhancement of coproducts (Several can be separated and sold at higher prices than currently realized).

## Ethanol From Cellulosics

- Short-term R&D needs:
  - Waste feedstock evaluation - highest priority
  - Systems analysis using data from waste feedstock evaluation
  - Demo plants for MSW, Ag residues, and forest residues using systems analysis results
  - New technologies, some of which might be used for demo plants.
- Long-term R&D needs:
  - Genetic development for higher production rates and yields - highest priority
  - New conversion technologies
  - Dedicated biomass for large-scale production
  - Integrated biomass production-conversion
  - Systems and risk/benefit analysis.